

# CLASSIFICATION OF TORBANITES AND RELATIONS TO ASSOCIATED CARBONACEOUS SEDIMENTS IN NEW SOUTH WALES.

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(Plate vi; two Text-figures.)

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## *Introduction.*

The classification of New South Wales torbanites has been approached, firstly, from the view-point of relations with associated carbonaceous sediments occurring in the coal-measures of the Kamilaroi System, and, secondly, with the object of a detailed classification of true torbanites.

The study of relations with associated sediments involves genetical and constitutional features, as well as physical and chemical properties, leading to a correlation between properties, genesis, constitution and relative economic importance of torbanite and its associates. In addition to the study of true types, research has been extended to embrace transitional phases and gradations, involving diagrammatic representation of constitutional variation.

In classifying the torbanite group, an attempt has been made to develop a system in which divisions and sub-divisions are based on variations of fundamental scientific importance, as well as being compatible with economic values. The classification has not been arranged to include the large variety of foreign oil shales; but relations between these and Australian types have been taken into consideration to provide for a possible extension of the scheme.

## NOMENCLATURE.

A great deal of confusion exists in the use of the terms oil shale, cannel coal, boghead cannel, boghead, torbanite and kerosene shale. Different writers have applied the same terms to different substances; and there does not appear to be any universally accepted nomenclature, although it is generally recognized by recent writers (Oil Shale and Cannel Coal, 1938) that there are several distinct types of material to which the above names have been unsystematically applied. The terms kerosene shale, oil shale and torbanite have been used in referring to the rich kerogen-bearing rocks occurring in the Kamilaroi Basin, and the name cannel coal has been used in confusion with these. The terms boghead and torbanite originated from the deposits at Boghead Swamp and Torbane in Scotland, and were applied to the same type of material. Cannel coal is derived from the name "candle coal" used for a special type of coal which burns with a bright, clear flame. It is intended to retain the use of the name torbanite in referring to sediments derived from algal sapropel, and to limit the use of the term cannel coal to sediments formed from vascular-plant sapropel. The name kerosene shale originated many years ago, when torbanite was treated, almost solely, for the production of kerosene. There seems to be no justification for its continued use, as other more important products are now being produced. The name oil shale has been applied to almost every type of rock which will produce oil when heated. Its use in this way has become so conventional that it would, perhaps, serve a good purpose to apply the term broadly to all carbonaceous sediments used for oil production, as against those which are used as solid fuel and come under the broad heading of coal.

## REVIEW OF PREVIOUS LITERATURE.

Genetical and constitutional research, in relation to the classification of coal (on which a considerable amount of literature is available) forms a useful background to similar problems connected with torbanite. It has long been recognized that there is a complete gradation in various ranks of coal, commencing with peat and passing through lignite, brown coal, bituminous rank and terminating in anthracite. The members of this series represent various stages in the process of coal evolution, brought about by metamorphism, dependent upon time and changing physical and chemical conditions which accompany the burial of organic material, originally deposited at the surface.

Early workers attempted to account for the different types of coal by assigning them to various stages in the evolutionary process. Later workers pointed out that coals, assumed to be of different rank, may occur associated in the same geological formation. The important fact was then established that different types of coal frequently belong to the same evolutionary rank, and that each rank contains types which are predecessors of coals in higher ranks. Thus it was recognized that the nature of the original organic debris, from which a coal is derived, plays an important part in determining its specific type.

Thiessen (1930) emphasized strongly the influence which different kinds of vegetation, forming the original organic debris, have upon the final products. He points out that sapropel originates in the open bog; that fibrous peats are derived from marsh conditions; that the angiosperm forest gives rise to an amorphous, humic peat, and a conifer forest to a very woody peat; that the end-products of bituminous rank, derived from these peats, would be cannel coal, pseudo-cannel, bright coal and woody coal. He also described common coal as consisting mainly of anthraxylon or matter derived from wood, but containing some attritus and only a small quantity of mineral matter (Thiessen, 1921). He considered cannels to be composed mainly, if not entirely, of attritus, with predominating spore material, some cellulosic degradation and resinous matter, and an ash content typically higher than that of the common coals.

White (1925, 1926) pointed out that common coals were formed mainly from terrestrial organisms of vegetable nature, laid down on land surfaces which were covered by shallow, freshwater swamps. He maintained that cannel coals represent accumulations of spores and pollen exines, set in a matrix consisting largely of colloidal humic derivative of terrestrial, carbohydrate origin. This sapropelic material was deposited in water too

deep to allow the growth of sub-aerial swamp vegetation, and so situated that only spores and pollen exines could find their way into it.

The consensus of opinion is that fundamental differences, in the original organic debris and the corresponding environments of deposition, give rise to differences in constitution which persist throughout the progressive stages of coalification, until the rank, equivalent to anthracite, is reached.

Several different conceptions, concerning the relations between torbanite and cannel coal, have been put forward by previous writers. Carne (1903) was of the opinion that Australian torbanites and cannel coals are closely related and represent divisions of a class, rather than different groups of substances. This view involves the idea of a common origin, with proportional modifications of the original constituents. Dixon (1888) put forward the theory that torbanites and cannel coals were derived from different types of organic debris, but developed under similar conditions of preservation. Ashly (1918), in discussing cannels of the United States, suggested a complete gradation from cannel into humic coal on one side, and boghead or torbanite on the other. Cunningham-Craig (1919) put forward the theory that oil shales, including torbanites, represent inspissated petroleum residues, while cannel and common coal are essentially the result of coalification of vegetable material.

White (1930) recognized two distinct types of peat: canneloid (spore peat) and boghead (algal saprocol). He claimed that the former gives rise to the various ranks of cannel coal, while the latter becomes typical boghead or torbanite. He also suggested (White, 1926) that it is possible to get a gradation from cannel coal either into torbanite or humic coal, depending on changes in environment of accumulation and the source of the organic debris. Thiessen (1930) suggested that cannels are formed from peat consisting largely of spores, cuticles and other resistant matter, while torbanite is produced from a peat in which algae predominate.

A classification of "Kerogen Rocks and Kerogen Coals", recently advanced by Down and Himus (1940), gives an excellent basis for differentiation between torbanite, cannel and common coal, on constitutional differences. It provides for a gradation from cannel to either torbanite or coal; but does not include a systematic classification of the torbanite group. Raistrick and Marshall (1939) have outlined a classification of coals, cannels and torbanites, emphasizing both macroscopic and microscopic constitutional relations.

It may be concluded that the general opinion of recent workers is that torbanite, cannel and common coal, with regard to constitution, form distinct classes of material as their respective peats resulted from the accumulation of unlike vegetable debris under different conditions, although the cannels and torbanites may be grouped, genetically, as sapropels. The developmental processes, following primary deposition, are considered to have advanced along parallel lines, giving rise to the various ranks of the three different classes of material.

#### RELATIONS BETWEEN TORBANITE AND ASSOCIATED CARBACEOUS SEDIMENTS IN NEW SOUTH WALES.

The variation of carbonaceous sediments, in evolutionary rank as well as constitutional type, means that a system of classification should include the development of different ranks, in addition to the relations between the types belonging to each rank. The following results and discussion on the classification of torbanite and its relations to associated carbonaceous sediments, is confined to materials of bituminous rank. Other ranks of torbanite do not occur in New South Wales, and (in dealing with the local deposits) the consideration of the bituminous rank meets all practical requirements.

#### *General Descriptions.*

The carbonaceous sediments associated with torbanite, consist of common coals, cannel coals, and carbonaceous shales. In dealing with relations between the four materials, brief, generalized descriptions of typical examples are given to clarify terminology, while fundamental differences and relations are discussed under separate headings. The descriptions of constitution, and conclusions regarding original organic debris and environment of accumulation, are based on the study of materials from the New South Wales Kamilaroi.



Common coals consist of bright and dull types, and indefinite forms of dirty and stony coal. They all exhibit well-developed cleat, and cleavage; usually possess banding; and burn readily, yielding a bituminous odour.

Cannel coals constitute a rather specialized group, quite distinct from common coals. They are black in colour; compact, fine grained and homogeneous in texture; possess a black, shining streak and poorly-developed cleat and cleavage; display either a bright or dull lustre; have a conchoidal to rectangular fracture; burn with a bright flame and bituminous odour, and produce large amounts of ash.

Carbonaceous shales include very low-grade coals, cannels, and clay shales carrying sufficient carbon to appear quite black in colour. They seldom possess cleat, but cleavage is usually well developed. They are fine grained and compact, with high specific gravity; possess a black to grey, earthy streak, and frequently become soft, when wet. They will not burn, but usually produce a faint bituminous odour, when heated.

Torbanites are compact, fine-grained materials, essentially homogeneous in texture, but occasionally show faint banding. The streak is always coloured, varying from dark brown to light yellowish-white, while the natural colour of the fracture-surface varies from black to dark blue-black and dark bottle-green. The fracture is conchoidal to irregular, and lustre varies from a bright to a dull, silky sheen. Torbanites never show cleat, but imperfect cleavage occurs in medium to low-grade types; they ignite readily, and burn with a bright flame, producing a waxy, aromatic odour, quite distinct from the odour of burning coal or cannel.

#### *Constitution and Original Organic Debris.*

*Torbanite*.—A detailed description of the micro-constitution and essential constituents of torbanite is given in a previous paper (Dulhunty, 1939).

Thin sections of torbanite, under a magnification of 30 to 50 diameters, show a definite, uniform structure, consisting of translucent organic bodies, separated by films of opaque matrix. The bodies are disc-shaped, appearing elongated or oval in vertical sections (Plate vi, B), and roughly rounded in horizontal sections (Plate vi, A and C). These bodies do not possess hard and well-defined margins, and tend to fray out into the opaque groundmass. The most abundant of the organic bodies are pale yellow in colour, and their substance has been referred to as "gelosite", while others, orange-yellow toned, are described as consisting of "retinosite".

Gelosite and retinosite are the oil-producing constituents of torbanite, frequently occupying as much as 90 per cent. of its volume. The two kinds of bodies, occurring side by side (Plate vi, C), are similar in all properties, except refractive index, specific gravity and colour. This suggests that their difference is biological rather than the result of varying conditions of preservation.

The matrix, termed "matrosite", is homogeneous and opaque, consisting of finely-divided mineral matter with a little free carbon. Small fragments of dark brownish-red material, visible in the matrosite under high power magnification (750 to 1,000 diameters), is referred to as "humosite", and occurs in very small quantities—less than one per cent. of the total volume.

The matrosite, surrounding gelosite and retinosite bodies, is usually continuous throughout the torbanite, and may be described as the matrosite skeleton but, in some cases, when the quantity is small, it occurs only as isolated fragments.

A detailed discussion on evidence, relating to the biological origin of gelosite and retinosite, is reserved for a later paper dealing with the origin of torbanite. For the present purposes it is sufficient to state that recent palaeo-botanical authorities accept the persistent and regular, internal structures of gelosite and retinosite as conclusive evidence that they are a fossil form of colonial, unicellular alga, similar to the living *Botryococcus Braunii*; and it is concluded that the original organic debris of torbanite consisted, essentially, of the non-vascular substance of an alga which flourished and accumulated under specialized swamp conditions.

*Cannel Coal*.—The constitution of cannel coal is quite distinct from that of torbanite. Thin sections show varying amounts of spore material and pollen exines, preserved in clear, structureless, yellow material, particles of brownish-red resin, and fragments of opaque mineral charcoal or fusain (Plate vi, E). Occasional isolated bodies of gelosite



may occur in cannel closely associated with torbanite (Plate vi, G). The nature of the groundmass of cannels varies considerably. In those types which possess bright lustre, high volatile content and low specific gravity, it may consist of dark red, translucent substance, banded parallel to the bedding, but otherwise structureless and homogeneous. It is more usual, however, to find this red, structureless substance in the form of continuous layers (Plate vi, D), running throughout a groundmass of minute particles of spores, resin, fusain and opaque and translucent mineral matter. The cannels with dull lustre, low volatile content and relatively high specific gravity, possess a dark grey groundmass, consisting of both opaque and translucent mineral matter and fusain. Generally speaking, the groundmass of cannels will always transmit some light in thin sections; and it can be resolved, by high power magnification, into translucent organic constituents, opaque, fusainized organic material, and both translucent and opaque mineral matter.

The organic constituents of cannel coal are of vascular-plant origin; and an occasional algal colony, found in cannel closely associated with torbanite, cannot be regarded as an essential constituent. The structureless, translucent material, occurring in the groundmass of the high-volatile types, appears to consist of more or less completely macerated, sub-aerial swamp vegetation. The spore material, pollen and resin, belong to both swamp and terrestrial plants.

*Common Coal.*—The constitution of the common coals is similar, in a general way, to the well-known English and American types of bright and dull bituminous coals. The banded constituents consist of vitrain, clarain, durain, and fusain, or anthraxylon and attritus in terms of American classification. The organic matter represents large quantities of coarse, vascular-plant tissue, frequently showing well-preserved cell structure, in the form of translucent and opaque carbonized substances. Varying quantities of fine material occur with the coarse plant-debris, including spore material, resin grains, and opaque and translucent mineral matter (Plate vi, H). Coals, lying directly in contact with torbanite, may carry isolated bodies of gelosite in the layers near the coal-torbanite junction. The organic matter of common coals is derived from many different forms of terrestrial forest and scrub vegetation, together with sub-aerial plants of swamps and marshes.

*Carbonaceous Shales.*—Carbonaceous shales consist mainly of translucent and opaque mineral matter, with small amounts of carbonized organic debris, in the form of minute fusain particles (Plate vi, F). The opaque mineral matter represents fine silt, and the translucent grains consist of crystalline minerals, varying in size from minute particles to 0.5 mm. in diameter. The larger grains frequently consist of carbonates or silica formed in the shale. Occasional spore fragments (Plate vi, J) and small pieces of resistant plant-tissue, showing cell structure, occur as yellow and red, translucent particles. Isolated algal colonies or gelosite may occur in carbonaceous shales which are interbedded with torbanite, or situated on the same horizon near a deposit of torbanite (Plate vi, J). Algal colonies have been found in shales which are remote from torbanite, but this is very rare. It is certain that the carbonized organic matter, normally present, represents finely-divided, fragmentary material, derived from vascular plants of both terrestrial and aquatic nature.

#### *Influence of Environment of Accumulation.*

The environment of accumulation, with regard to deposition of organic debris, may be described as the combined influence of all physical and geographical factors. It controls selective deposition, and plays a major part in the ultimate nature of the carbonaceous material formed.

In common coals, the large quantities and coarse nature of the terrestrial debris indicate accumulation on surfaces, alternating between dry land and aquatic conditions, or accumulation in permanently submerged areas which receive terrestrial debris, transported by large volumes of water and strong currents.

The cannels consisting of both transported and indigenous organic matter—such as finely-divided and macerated debris, well-preserved, spore material and soft, sub-aerial swamp-vegetation—evidently accumulated in areas permanently covered by shallow water.

This prevented the growth of terrestrial flora, but allowed sub-aerial swamp-plants to flourish. The water currents, flowing into the area, were too weak to carry heavy land-plants, but were sufficient to transport pollen, spores, the light products of decay, and inorganic silt. Those cannels consisting entirely of transported material, including completely macerated debris and well-preserved spore material, were evidently deposited in deeper water which prevented the growth of sub-aerial as well as terrestrial plants. Inflowing currents, however, were sufficient to carry the finer, vascular-plant debris, which predominated in quantity over the truly aquatic flora growing there. Spore material and pollen grains may be carried by wind into all areas of deposition, and many of the special types of coal and cancell, containing large quantities of these materials, probably originated in this way.

The small quantity of finely-divided and carbonized organic matter in the carbonaceous shales, and the absence of recognizable plants—either aquatic or sub-aerial—suggest two alternatives: (a) accumulation in deep water, with the absence of strong, inflowing currents, accompanied by conditions unfavourable for the growth of aquatic plants, or (b) very rapid deposition of silt, containing fine, decaying vegetable matter, in swamps or areas of shallow water. These conditions would explain the occurrence of carbonaceous shale bands, interbedded with coal, cancell and torbanite.

In the case of torbanite, the organic matter is specialized and non-vascular. This, and the absence of terrestrial and sub-aerial, vascular-plant remains, indicates the growth of the alga within the area of the deposit, under conditions excluding both indigenous and transported vascular-plant debris. This would require water, too deep to allow the growth of sub-aerial swamp-plants, and free from inflowing currents, capable of transporting anything other than fine, suspended clay or colloidal products of organic decay. Alternatively, it would require the sudden covering of a surface—either dry land or old swamp-bed—with still water, in which the alga developed at a rate sufficient to form algal sapropel before swamp vegetation could become established.

*Properties in Relation to Constitution and Original Organic Debris.*

*Physical and Optical Properties.*—The physical properties of normal torbanite, cancell, coal and carbonaceous shale can be correlated with constitution, and thus related to the nature of the original organic debris.

The light-coloured streak of torbanite is caused by the presence of gelosite and retinosite, derived from algal material, while the black, shining streak of the coals and cannels is due to fusainized tissue and the fact that the translucent constituents (such as vitrain), derived from vascular-plant tissue, give a black powder when crushed. The silky sheen of torbanite and the bright, waxy lustre of coal and cancell may be related, respectively, to the bright fracture-surfaces of the individual bodies of gelosite and retinosite and the compact nature of the homogeneous, vascular-plant material.

Cleavage, parallel to the bedding, in coal is due to the banded constituents, foliated nature of the original debris and compression normal to the bedding plane. In cancell and carbonaceous shale, it is a function of sedimentary lamination and compression. The imperfect cleavage of torbanite results from the disc-like shape and orientation of the gelosite and retinosite bodies, caused by the collapse of algal colonies in the sapropel and compression after burial.

The presence of well-developed cleat, exhibited by coals and some cannels, appears to be connected, in some way, with the physical behaviour of vascular-plant debris, during natural carbonization; its absence in torbanite indicates that the algal material does not behave in the same manner. The lack of cleat, in carbonaceous shales, is due to the small amount of plant debris present. Flexibility and toughness are outstanding features of torbanite, due to similar properties possessed by gelosite and retinosite.

Some specialized properties, providing additional evidence of the difference between torbanite and associated materials, have been investigated by the writer (Dulhunty, 1941a). It was shown that the algal substance of torbanite will transmit considerable amounts of infra-red radiation through sections up to 1.0 mm. in thickness, and visible light through a thickness of 0.1 mm., while vascular-plant remains of cancell and coal are opaque to infra-red and visible light in sections more than 0.1 and 0.015 mm. in thickness, respectively.

In addition to the normal effects of double refraction, gelosite and retinosite, in thin, vertical sections of torbanite, exhibit a type of "cross hatching" or rectangular arrangement of polarization laminae (Dulhunty, 1939). The laminae appear when the bedding plane makes an angle of about 27°, on either side of the vibration direction of one of the nicols. Each elongated section of gelosite and retinosite behaves in a similar manner, so that all exhibit their polarization laminae at the one time in the same direction, giving the effect of optical continuity. The translucent constituents of cannel and coal frequently exhibit anisotropism, but the phenomenon of polarization laminae has been observed only in the organic matter of torbanite.

Thermal expansion of torbanite has been investigated in some detail (Dulhunty, 1941b). The coefficient of expansion in any one deposit varies for specimens of different quality, and also varies for specimens of the same quality from different deposits. It is always maximum at right angles to the bedding plane, and minimum in a parallel direction. When torbanite is heated and cooled, a certain amount of permanent linear deformation is caused. This is positive in a direction normal to the bedding, as the material does not contract to its original dimension on cooling—due to the development of permanent expansion. In directions parallel to the bedding, deformation is negative, the material returning to less than its original dimensions—due to the development of permanent contraction. Negative and positive deformation, in directions related to the bedding plane, is a characteristic feature of torbanite, and, as far as can be ascertained, is not known to occur in any other naturally-occurring or artificial material. Cannels and common coals expand only slightly at temperatures below those causing thermal decomposition; and they exhibit no evidence of the permanent deformation associated with thermal expansion of torbanite.

The foregoing results provide further evidence regarding the fundamental difference between torbanite and other carbonaceous sediments, and emphasize the specialized nature and properties resulting from the presence of algal material and its constitutional arrangement in torbanite.

*Chemical Properties.*—The chemical relations between torbanite, coal and cannel can be considered only empirically, owing to the lack of data concerning the exact chemical nature of the algal and some vascular constituents. Ultimate and proximate compositions, typical of the three types, are shown in Table 1. When materials of the same metamorphic rank are compared, the carbon/hydrogen ratio is greatest for the common coals, somewhat lower for the cannels and lowest for torbanite.

TABLE 1.  
*Ultimate and Proximate Analyses Typical of Torbanite, Coal and Cannel.*

Type of Material.	Proximate Analysis.				Ultimate Analysis.					Vol. to F. Carb. Ratio.	$\frac{C}{H}$
	Moist.	Vols.	Fix. Carb.	Ash.	C.	H.	O.	N.	S.		
Torbanite ..	0.5	60	10.0	29.5	85.0	10	4.0	0.7	0.3	6.00	8.5
Cannel ..	1.5	27	31.5	40.0	83.5	7	6.5	1.0	2.0	0.86	12.0
Coal ..	3.0	33	49.0	15.0	82.0	5	8.0	1.4	3.6	0.69	16.0

It is evident that torbanite contains more hydrogen, available for the formation of hydrocarbons, during thermal decomposition than coal or cannel, and, consequently, its ratio of oil/organic matter (by wt.) is highest. Proximate analyses provide important data, concerning the ratio of volatile/fixed carbon, which is always greater than unity for torbanite, and less for coal and cannel. Oxygen and nitrogen are highest in coal, less in cannel and lowest in torbanite. The sulphur content is variable, owing to the presence of metallic sulphides, which may occur in all carbonaceous sediments. The inherent sulphur content of the organic matter is relatively low for torbanite and higher for coals and cannels.

Important differences exist in the chemical nature and quantity of liquid hydrocarbons, produced by pyrolysis. The algal matter of torbanite gives a large yield of *oil*



with a high aliphatic content, while the vascular-plant material of coal and cannel produces small quantities of *tar* which is essentially aromatic. This is due to the different ultimate compositions and molecular structures of the organic constituents, and means that torbanite oil can be converted to petrol by thermal cracking, while tar from cannel and coal must be hydrogenated.

The organic matter of torbanite is insoluble, and that of coal and cannel only slightly soluble in common, organic solvents at their boiling-points, under atmospheric pressure. Recent experimental work, carried out by the writer (Dulhunty, 1942*a*, 1942*b*, 1943), has shown that the organic matter of torbanite can be rendered soluble by heating at temperatures between 280° and 340° C., which are lower than those causing thermal decomposition; and that the change to the soluble form does not involve evolution of volatiles or gas formation. Soluble products, thus formed, are very heavy hydrocarbons which can be converted to paraffins and olefines, by cracking. The solubilities of coal and cannel are not increased by heat treatment, indicating important structural differences in the organic matter of these materials and torbanite.

*Economic Uses.*—The different chemical properties of carbonaceous sediments, largely determine their economic uses. Torbanite is used for the production of oil and allied products; cannel, sufficiently rich in volatiles, for oil and, at times, gas production; coal as solid fuel in steam raising, and as raw material for gas production. Carbonaceous shales have no particular economic uses, apart from brick-making, which depends on their inorganic content rather than the properties which relate them to coals and torbanite.

#### *Correlations and Summary of Interrelations.*

The foregoing data and discussion, concerning relations of torbanite to associated sediments, indicate definite well-marked differences between algal material and the several varieties of vascular-plant remains. In each case, correlations are possible between properties, environment of accumulation, nature of original organic debris, micro-constitution and economic uses. This is summarily outlined in Table 2, showing the manner in which the characteristic chemical and physical properties of the four types are related, through micro-constitution, to environment of accumulation and nature of original debris. The table also shows, in each case, the relations of general properties to economic importance, and illustrates the determination of the latter, by the influence of genetical factors on micro-constitution. For example, the production of crude oil from torbanite and the fact that it is used as cracking stock are related to chemical properties, including low carbon/hydrogen ratio of the organic matter and high aliphatic content of the oil, respectively. These features are determined by the constitutional factor involving the presence of gelosite and retinosite, while the constitution itself is dependent upon genetical features embodying the deposition of non-vascular, algal sapropel. Similarly, the use of coal, in hydrogenation and the manufacture of gas and tar, is related to high carbon/hydrogen and low oil/organic matter ratios; to the presence of vitrain, clarain and durain; and to the accumulation of coarse, vascular-plant remains.

For the purpose of classification, it may be concluded, from the economic view-point, involving uses and quantity and nature of products, that torbanite must be regarded as distinct from other carbonaceous sediments, while, scientifically, it stands in a class by itself, both genetically and constitutionally. It is, however, related through the sapropelic condition of its organic debris to the cannels and carbonaceous shales; but its environment of accumulation differs in important details from that of the vascular-plant sapropels.

#### *Study of Transitions and Gradations between Types.*

The pure nature of the algal material in torbanite is a characteristic feature of the New South Wales deposits. In general, any fragment of vascular-plant tissue must be regarded as an accidental occurrence, standing in the same relation to torbanite as an isolated algal colony does to coal, cannel or carbonaceous shale. There are, however, rare occurrences of material which can be regarded as transitional, in constitution, between torbanite and either coal, cannel or carbonaceous shale. The study of such transitions is important, as it throws light on problems involving the intermingling of

TABLE 2.  
*Correlation between Properties, Genesis, Constitution and Economic Importance of Torbanite, Connell and Coal.*

Carbonaceous Sediments.	Conditions of Original Organic Debris Controlled by Environment.	Nature of Original Organic Debris.	Micro-constitution.	Physical and Optical Properties.	Chemical Properties.	Economic Importance.
Torbanite.	Sapropel.	Algal, non-vascular.	Gelosite, retinosite bodies in matrix of matrosite with small amount of humosite.	Dull to bright silky sheen, light streak, no cleat, imperfect cleavage, high thermal expansion and flexibility. Relatively transparent to infra-red and visible light.	C/H low. Vol./F.C. > 1. Oil/organic matter high. Oil: relatively high aliphatic content.	Production of crude oil used as cracking stock for conversion to petrol.
Connell.	Sapropel.	Vascular.	Spores, pollen, resin, fine fusain in matrix of clay or translucent humic derivative.	Dull to bright waxy lustre, black streak, imperfect cleat, good cleavage, medium thermal expansion and flexibility, relatively opaque to infra-red and visible light.	C/H medium. Vol./F.C. < 1. Oil/organic matter medium. Tarry oil: relatively low aliphatic content.	Production of light, tarry oil suitable for hydro-generation (rarely cracking) to light fuel or petrol; rarely used for gas.
Carbonaceous shale.	Sapropel.	Vascular.	Fine, inorganic material, limited spores, resin, pollen, carbonaceous plant tissue.	Dull lustre, black to grey earthy streak, high specific gravity, no cleat, good cleavage, low thermal expansion and flexibility. Optical transparency due to crystalline mineral matter.	High ash content, gives bituminous odour when heated, will not burn. Oil and gas: a trace to oil.	Minor use in brick-making, otherwise unimportant.
Common coal.	Coarse plant remains.	Vascular.	Vitrinite, charinite, fusinite, durinite, crystalline mineral matter.	Dull to bright waxy lustre, black streak, good cleat and cleavage, medium thermal expansion and flexibility, relatively opaque to infra-red and visible light.	C/H high. Vol./F.C. < 1. Oil/organic matter low. Tar: essentially aromatic.	Gas manufacture, by-products, coke, coal tar, solid stock for hydro-generation.

two sets of conditions, the demarcation between areas of different environment, and the differentiation of organic sediments into specific groups.

*Occurrence and Nature of Transitional Types.*—A transition from torbanite to bituminous coal occurs at the western margin of one of the Katoomba torbanite deposits (Mort's Upper Seam) at the West Head of Nellie's Glen. The torbanite seam gradually changes to bituminous coal, over a distance of about 30 chains, without appreciable variation in thickness. Specimens collected from the middle of this transition, possessed good cleavage, poorly-developed cleat, and a banded appearance, similar to that of bright coal; but the lustre was a silky sheen, and the streak was dark brown, resembling that of torbanite. Microscopic examination revealed typical algal bodies, set in a groundmass of dark red, translucent material, in the form of continuous laminae running parallel to the bedding (Plate vi, D), and small, irregular fragments of fusainized tissue. The translucent laminae represent partially-macerated, vascular-plant debris, probably belonging to sub-aerial swamp vegetation. This unusual type represents a phase, transitional between torbanite and bituminous coal. The original organic debris consisted of both algal colonies and soft, vascular-plant tissue. The environment of accumulation evidently permitted the development of algal colonies, as well as the growth of swamp-vegetation. The algal remains eventually became embedded in the vascular-plant tissue, followed by the preservation of both.

Examples of material, transitional between torbanite and cannel coal, have been found in several deposits, but it is not common, and occurs only in thin bands. Specimens of this material have been collected from the Glen Davis and Wollar Deposits. They possess poorly-developed cleat, medium-bright lustre (somewhat silky), and a dark brown, shining streak. Thin sections show algal colonies distributed evenly throughout a fine mosaic of mineral grains, opaque particles of fusain, translucent spore material, dark red resin, and fragments of vascular-plant tissue. The environment of accumulation, giving these transitions, must have approximated to that of normal torbanite-formation, but it allowed the introduction of cannel sapropel by water currents or aerial transportation. An example of material transitional between torbanite and cannel coal is shown in Plate vi, G.

Material, intermediate between torbanite and carbonaceous shale, is the most common of the transitional types. It is frequently associated with low-grade torbanite, being characterized by relatively-high specific gravity, dull lustre, dark brownish-grey streak (somewhat earthy), poor cleavage and no definite cleat. It usually consists of algal colonies, embedded in a matrix of opaque and translucent mineral matter and particles of free carbon, together with occasional fragments of vascular-plant tissue, resin and spore material (Plate vi, J). The environment producing these types must have favoured the development of a limited quantity of alga, but permitted the introduction of silt—containing some decayed vegetable matter—under conditions already described for the deposition of normal carbonaceous shales.

Types have been observed transitional between carbonaceous shale, cannel coals and coals. These are intermediate in constitution between the true types, and evidently originated by the blending of the normal conditions, typical of each.

The existence of types transitional between torbanite and the associated carbonaceous sediments, indicates that, under certain circumstances, the specialized conditions of torbanite-formation have intermingled with surrounding conditions. The majority of transitions have been observed at the margins of deposits. This would be expected, as the intermingling of environments would be most likely to occur where two distinct sets of conditions meet. The writer has not been able to establish an occurrence in which the whole of a lenticular deposit (representing all the sediments accumulating in a lake or swamp, under one set of conditions) consists of a transitional type. This would suggest that the conditions necessary for the development of algal sapropel, and those which produce each of the other carbonaceous sediments, were, in the main, mutually exclusive, and that the intermingling of conditions was a marginal and, more or less, accidental feature.

The transitions described above are *lateral* changes from torbanite to other materials, due to merging of conditions on one plane of deposition. *Vertical* transitions



are also known, involving a gradual change in type from one horizon of deposition to another, but they are very rare; and the vertical interval, over which the transition occurs, is usually limited to less than one inch. In such cases, the small, vertical extent of transitional material suggests that the gradation may have been caused by mechanical mixing of the two ingredient debris at their plane of contact, rather than being due to true intermingling of conditions. The line of demarcation, between torbanite and an overlying or underlying bed, is usually so sharp that the change can be studied within one microscopical field, as illustrated in Plate vi, I).

*Volumetric Estimation of Constituents.*—Diagrammatic treatment of transitions and the study of intermediate types require the accurate determination of relative amounts of different constituents present in the materials concerned. A method of optical, volumetrical analysis, developed by the author, has already been described (Dulhenty, 1941a). The small size of many organic constituents necessitates microscopical methods of determination. The technique adopted involves the use of a mechanical stage fitted with an integrating micrometer on a microscope giving a magnification of about 100 diameters. A line is taken across the full width of the thin section (vertical to the bedding); and the sums of the small distances, occupied by the different constituents, are determined along the line. The percentages, by volume, are then calculated for each constituent. Estimations are made along several lines across each section; and the results are obtained quickly and easily, with an error of no more than one per cent.

The thickness of the transparent sections is an important factor, upon which the success of the method depends. In the case of torbanite, the ellipsoidal shape of the gelosite and retinosite bodies and the fact that they are embedded in an opaque matrix mean that the area, which they occupy, will increase as the thickness of the section decreases. It has been shown that all sections must be reduced to less than 0.01 mm., before estimating the percentages of constituents. The same applies to cannel, coals and carbonaceous shales, owing to the minute size of some spores and fragments of resin and plant tissue.

*Diagrammatic Illustration of Gradations between Types.*—In the lateral transitions, the development of intermediate types by intermingling of organic debris within the marginal areas of transition, and the development of true types under normal conditions, involve four variable factors in constitution. Three of these are the organic constituents: algal sapropel, vascular-plant sapropel and coarse vascular-plant remains, while the fourth is mineral matter. The true types—torbanite, cannel and coal—contain only one organic variable, and mineral matter. Transitional types may contain any two of the three organic variables, together with mineral matter. Thus, the inorganic variable—mineral matter—enters into the composition of both true and transitional types; and when it rises to the vicinity of 85%, the material becomes a carbonaceous shale—irrespective of the nature of the organic matter present.

A type, containing all three organic variables and mineral matter, is theoretically possible; but such material, intermediate in constitution between the four organic sediments, has not yet been encountered.

An attempt has been made to illustrate constitutional relations by means of a variation diagram, upon which all possible types—both pure and transitional—may be plotted, according to their composition. The construction and properties of this diagram are shown in Fig. 1. It possesses three axes, AX, BX and CX, making angles of  $120^\circ$  at the centre. These represent the three organic variables: algal sapropel (torbanite), vascular-plant sapropel (cannel) and coarse vascular-plant remains (coal), respectively. The proportion of each is given, within appropriate areas on the diagram, by perpendiculars to the axes at points equivalent to their respective percentages (see percentages along AX). The three composition triangles, aXb, cXa' and b'Xc', are formed by the three lines, aa', bb' and cc', perpendicular to the axes, A, B and C, respectively, at their common zero point, X. In any one of these triangles, the proportions of the two organic variables are given by perpendiculars on the two adjacent axes, and the proportion of mineral matter is given by percentage lines, parallel to the base of the triangle (see triangle cXa'). The percentage lines represent perpendiculars on the negative projection of the remote axis, belonging to the third organic variable, which does not enter into

the composition of points in the triangle concerned. Thus, at any point in one of the composition triangles, the proportions of the two, constituent, organic variables are equivalent to intercepts made on their axes by perpendiculars from the point; and the amount of mineral matter is represented in terms of the negative value of the third organic variable. It follows that the mineral content is actually given by the distance from the base of the triangle, using the inverse scale employed on the axes.

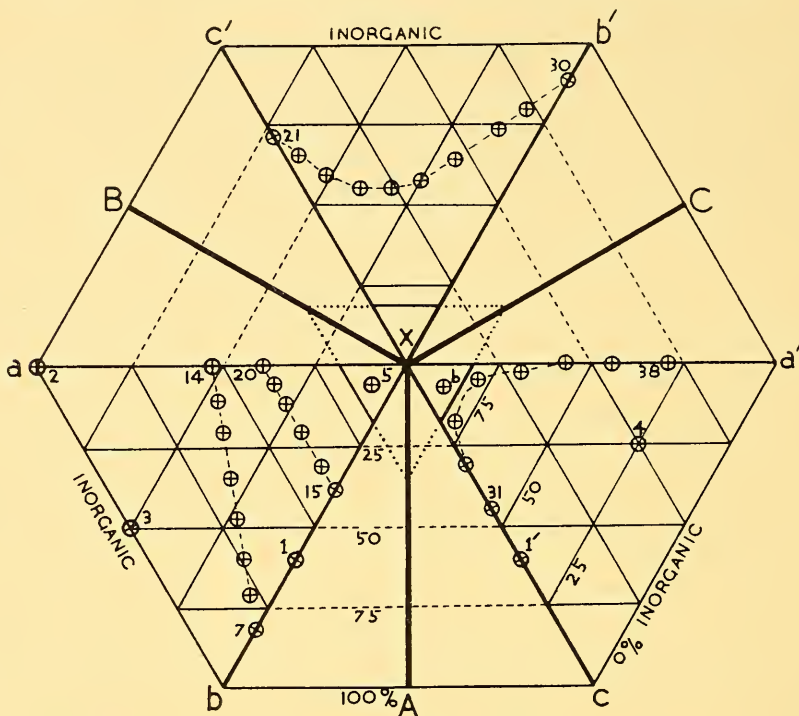


Fig. 1.

Construction and properties of variation diagram used in the study of materials transitional between torbanite, cannel, coal and carbonaceous shale.

Pure types (containing only one organic variable and mineral matter) will fall along the lines meeting at X and forming two sides of each composition triangle, as points on these lines can contain only one organic variable. The points 1 and 1' both represent a pure type containing 60% of A and 40% of mineral matter, as they are situated on bX and cX (the zero perpendiculars to the axes B and C); both lie on the 60% perpendicular to the axis AX; and both fall on the 40% mineral lines in the composition triangles on either side of AX. Thus, the point representing a pure type will appear on the sides of the two composition triangles, adjacent to the axis corresponding to the organic matter of the type. If the point 1 moves into the triangle aXb, it then represents a transitional type containing A, B and mineral matter. If it moves into the triangle cXa, the type becomes transitional between A and C. All points within the small triangle, shown by dotted lines about the centre X, will represent carbonaceous shales.

Three pure types, containing 100% of an organic variable, are theoretically possible. These would fall at the points (b and c), (a' and b') and (c' and a), as illustrated by point 2, which represents a material containing 100% of B. Transitional types, containing 50% of each of two organic variables, are also theoretically possible, as illustrated by point 3. Point 4 is an example of a transitional type containing 50% of C, 25% of A and 25% of mineral matter. Point 5 would be a carbonaceous shale containing 90% of mineral matter, 5% of A and 5% of B. Similarly, point 6 would be a carbonaceous shale containing small quantities of both A and C.

The nature of a gradation from one pure type to another, exhibited by a series of specimens taken from different points in a seam, may be shown on the diagram by plotting the points corresponding to each specimen. Four theoretical gradations are illustrated by this means in Fig. 1. The points 7 to 14 represent a passage between the pure types A and B, accompanied by a constant increase in the mineral content; and the series 15 to 20 show the same transition, without change in mineral content. The points 21 to 30 illustrate a gradation between pure types B and C in which the mineral matter first increases rapidly, then decreases slowly. The fourth theoretical gradation is shown by the points 31 to 38. In this case, the mineral content of the pure type A, first increases from 58% to 64%, then the organic variable C commences to come in with further increase in mineral matter. Finally, the mineral content decreases as the organic variable A is excluded, and the pure type C continues to become richer in organic matter.

The use of this diagram to illustrate results actually obtained by optical, volumetrical analyses of transitional and pure types is shown in Fig. 2. The composition of eight types, A to J, excluding B and I, illustrated by photo-micrographs in Plate vi, have been plotted on the diagram using corresponding letters in small capitals. The

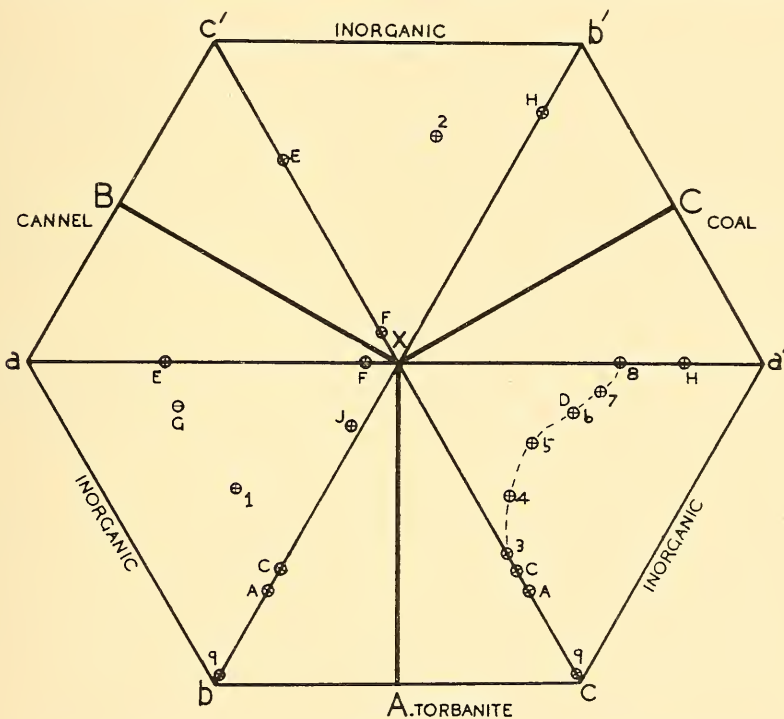


Fig. 2.

Variation diagram illustrating gradations, and types transitional between torbanite, coal, cannel and carbonaceous shale.

Points on diagram (shown by circle and cross).

- A. Torbanite; Pl. vi, A.
- C. Torbanite; Pl. vi, C.
- D. Transitional type, torbanite-coal; Pl. vi., D.
- E. Cannel coal; Pl. vi, E.
- F. Carbonaceous shale; Pl. vi, F.
- G. Transitional type, torbanite-cannel coal; Pl. vi, G.
- H. Common coal; Pl. vi, H.
- J. Transitional type, torbanite-carbonaceous shale; Pl. vi, J.
- 1. Transitional type, torbanite-cannel coal.
- 2. Transitional type, common coal-cannel coal.
- 3 to 8. Gradation from torbanite to common coal.
- 9. Richest known torbanite, Marangaroo, N.S.W.



pure torbanites, A and C, fall along the zero perpendiculars on either side of the axis AX. Similarly, the pure cannel, E, and coal, H, fall on either side of their axes. The carbonaceous shale, F, containing 92% of mineral matter, is shown on the zero perpendiculars on either side of the axis BX, as the carbonized plant-remains are derived from vascular sapropel. The type J, transitional between torbanite and carbonaceous shale, falls close to the 85% mineral line, and the small amount of vascular sapropel, in the form of a spore fragment, is indicated by its position between the zero perpendiculars bX and aX. Material, transitional between torbanite and cannel coal, is shown by the point G, at the position determined by its constitution, within the composition triangle aXb; and the type, transitional between torbanite and coal (point D), is shown within the triangle cXa'. The passage from torbanite to coal (described earlier), which occurs at the margin of Mort's Upper Seam (West Head of Nellie's Glen, Katoomba), is illustrated in Fig. 2 by the series of points 3 to 8 which represent the compositions of six specimens collected at equal distances along the outcrop. The arrangement of points shows an increase in mineral content, as the environment of torbanite-deposition commences to intermingle with the coal-forming conditions. The later stages of the transition show a decrease in mineral matter, as the environment continues to change, and coarse, vascular-plant remains increase in quantity, to the exclusion of algal sapropel.

Lenses of material, transitional between torbanite and cannel coal, occur in the Glen Davis Deposit. The constitution of a specimen from one of these lenses is shown by point 1 on the diagram. An example of a type (collected from the Dirty Seam in the Burragorang Valley), intermediate between cannel and coal, is illustrated by point 2. The richest torbanite yet found in Australia occurs as a lens, at the top of the main seam in the Marangaroo Deposit (Cane, 1943). This material contains 1.8% of ash, but practically no mineral matter introduced as silt or clay during the formation of the deposit. Its composition, indicated by point 9 on the diagram, approximates to the theoretically possible type containing 100% of algal sapropel.

#### CLASSIFICATION OF TORBANITES.

##### *Genetical Correlation of Variable Properties.*

*The Variable Properties.*—Torbanite may be considered to include all those materials which consist, essentially, of algal sapropel and finely-divided mineral matter in varying proportions, having accumulated in an environment which was incompatible with the deposition of vascular-plant remains.

It is well known that the normal torbanites of the New South Wales Permian vary considerably, in both physical and chemical properties, as well as economic values. The streak may vary from light yellowish-white to dark brown; the lustre from bright to dull; the fracture from conchoidal to rectangular; and the oil yield from high to low. Little has been known, however, concerning the relations between different properties, the fundamental causes of variations and their relations to constitutional and genetical factors. These problems have been investigated by the writer in considerable detail, with the object of developing a classification of torbanites.

The principal macroscopic variations of torbanite are: streak, lustre, colour, diaphaneity, texture, fracture, cleavage and specific gravity. The microscopic variations include features associated with micro-constitution, such as the arrangement and optical and physical properties of the essential constituents. The chemical variations include the total oil and gas yields, the proximate composition, coking properties, and several ratios, such as volatile/fixed carbon, oil/organic matter and oil/gas (by wt.).

*Fundamental Influencing Factors.*—It has been found that certain properties may be grouped together, as their variations are interrelated or co-dependent upon common, influencing factors, and that these factors are fundamentally related in the formation of torbanite. There are three common, influencing factors which control all the variable properties and determine the differentiation of torbanite into different types. These three factors, the groups (A, B and C) of variable properties which they control, and the extent of variations, are set out in Table 3.

TABLE 3.  
*The Influence of Genetical and Constitutional Factors on the Variation of Properties in Torbanite.*

Group.	Property.		Chemical.	Variation.		Common Influencing Factor.
	Macroscopic.	Microscopic.		Leucoeratic Types. (Eukerogenic Constituents.)	Melanocratic Types. (Dyskerogenic Constituents.)	
A	Streak.			Light yellowish-white to med. yellow.	Brownish-yellow to dark brown.	<i>Environment of Accumulation.</i> Variations in physical conditions during accumulation giving different forms of algal debris—resulting in different types of torbanite, i.e. leucoeratic and melanocratic torbanite containing eukerogenic and dyskerogenic constituents, respectively.
	Colour.			Dark green to dark brown.	Dark bluish-black to black.	
	Colour of gel, and resin, in 0.01 mm. sect.			Gelosite: pale yellowish-white. Refinosite: light orange-yellow.	Gelosite: pale brownish-yellow. Refinosite: light reddish-yellow.	
	Transmission of visible light and infra-red.			Large amounts transmitted, i.e. low optical density.	Small amounts transmitted, i.e. high optical density.	
			Ratio of Vol./F. Carbon.	Ratio is high. Vol./F. Carbon = 6.5 to 20.	Ratio is low. Vol./F. Carbon = 1 to 10.	
			Ratio of Oil/Org. Matter (Wt.).	Ratio is high. Oil/Org. Matter = 0.7 to 0.92.	Ratio is low. Oil/Org. Matter = 0.5 to 0.8.	
			Ratio of Oil/Gas (Wt.).	Ratio is high. Oil/Gas = 9.5 to 30.	Ratio is low. Oil/Gas = 4 to 10.	
B	Degree of lustre.			<i>a.</i> Cont., (—) and (+) and (S) give dull lustre. <i>b.</i> Isol., (—) to (med.) and (S) and (H) give bright lustre. <i>c.</i> (H), Cont., (—) and (+) give bright lustre.		<i>Environment of Accumulation and Preservation.</i> Opaque matrix. Abundance, hardness and arrangement of matrosite dependent upon quantity of silt introduced, and inorganic cementation. (—), small quantity of matrosite, (med.), medium quantity of matrosite. (+), large quantity of matrosite. (S), soft matrosite. (H), hard matrosite. Cont., continuous skeleton. Isol., isolated fragments.
	Diaphaneity.			<i>a.</i> Isol., (—) to (med.), (S) and (H) give slight transparency at thin edges. <i>b.</i> Cont., (—) and (+), (S) and (H) give complete opacity in land specimens.		
	Texture.			<i>a.</i> (S) and (H), (—) to (med.), Isol. give smooth surface. <i>b.</i> Cont., (S), (—) to (+) give rough surface. <i>c.</i> Cont., (H), (—) to (+) give smooth surface.		
		Micro-constitution.		<i>a.</i> Cont. gives regular arrangement of algal bodies. <i>b.</i> Isol. gives tendency for algal bodies to coalesce into continuous mass.		
		Caking properties.		<i>a.</i> Isol., (—) to (med.) torbanite fuses forming coherent coke. <i>b.</i> Cont., (+) gives incoherent or slightly coherent coke. <i>c.</i> Cont., (—) to (med.) gives slightly coherent if soft, completely coherent coke if hard.		
		Thermal decomposition.		(med.) to (+) containing large amounts of humosite reduce ratios for Vol./F. Carbon, Oil/Org. Matter and Oil/Gas.		
	Specific grav.			(+) gives high, and (—) gives low specific gravity.		
C	Fracture.			(—) gives even fracture controlled by bedding; (+) gives conchoidal fracture independent of bedding.		<i>Environment of Accumulation.</i> Gelosite and refinosite. Abundance dependent upon conditions of accumulation. (—), small quantity. (+), large quantity.
	Type of lustre.			If lustre is bright then (—) gives silky sheen and (+) gives waxy sheen.		
			Ash content.	In general, (—) gives ash content above 35% and (+) gives ash content 35% to 1.8%.		
			Oil yield.	Abundance of algal material controls yield of oil per ton of torbanite for any given ratio of Oil/Org. Matter.		
			Proximate composition.	Abundance of algal material controls results of proximate analysis for any given ratio of Vol./F. Carbon.		
	Cleavage.			(—) gives well-developed cleavage, (+) gives poorly-developed cleavage.		

*Group A.*—The variable properties, associated in Group A of this table, are all determined by the existence of two different forms of the predominating constituent, gelosite. The cell structure and general morphology of the alga are identical in all cases; but the gelosite varies, in different deposits, from pale yellow to brownish-red, when examined in micro-sections of the same thickness. Torbanites, containing light-coloured gelosite, are characterized by light yellowish-white to medium yellow streak, dark green or brown colour, high ratios of volatile/fixed carbon, oil/organic matter and oil/gas. Those containing dark-coloured gelosite possess dark brown to brownish-yellow streak, are black to bluish-black in colour, and give comparatively low figures for the three chemical ratios mentioned above. The light- and dark-coloured forms of gelosite possess low and high optical densities, respectively, with regard to transmission of visible light and infra-red radiation. It is evident that the two forms of gelosite, responsible for the foregoing variations in properties, must play an important part in the classification of torbanites. It is suggested that the terms *leucocratic* and *melanocratic* should be adopted, in referring to torbanites containing light- and dark-coloured gelosite, respectively.

The association of high and low chemical ratios with leucocratic and melanocratic types, means that the gelosite of leucocratic torbanite produces more oil than that of the melanocratic type. This fact is important, concerning economic as well as purely scientific requirements in classification; and it is suggested that the organic matter of leucocratic torbanite should be referred to as the *eukerogenic* form, and that of melanocratic torbanite as the *dyskerogenic* form.

*Group B.*—The properties associated with Group B are influenced by the opaque matrix consisting mainly of matrosite. The properties affected are: degree of lustre, macroscopic diaphaneity, texture, micro-constitution, coking properties, and, to some extent, thermal decomposition. The opaque matrix causes these properties to vary by virtue of its hardness, abundance and arrangement. The last term refers to the occurrence of the matrosite, either as a continuous skeleton or as isolated fragments. The nature of the variations involved is summarized in Group B of Table 3. Hard matrosite, forming a continuous skeleton, produces bright lustre by causing the gelosite and retinosite bodies to fracture when the torbanite is broken, thus exposing the bright lustre of these constituents. Soft matrosite allows the fracture-surface to pass round the algal bodies, resulting in dull lustre. Large quantities of matrosite reduce the area of algal material exposed in the fracture-surface, and tend to reduce the brightness of the lustre. If the matrosite occurs in isolated fragments, the fracture-surface must pass through the algal bodies, producing bright lustre.

Macroscopic diaphaneity, mentioned above, refers to the slight degree of translucency, exhibited by some torbanites, at the thin edges of handspecimens. This translucency is due to the occurrence of matrosite as isolated fragments, allowing light to be transmitted by the translucent constituents. If the matrosite forms a continuous skeleton, each translucent body is surrounded by matrix, causing complete opacity in handspecimens. The difference in hardness between the matrix and algal bodies, together with the arrangement of the matrosite, influences the nature of the fracture-surface, in a manner similar to their effect on lustre. The influence on micro-constitution depends on the arrangement of matrix. A continuous skeleton of matrosite gives an opaque film, surrounding each algal body, while its occurrence as isolated fragments allows the bodies to coalesce into a continuous mass, as indicated in the table. The specific gravity of torbanite becomes higher with increasing quantities of matrosite, as this constituent consists largely of mineral matter.

Variations in coking properties are caused by abundance, arrangement and hardness of matrosite. If the matrosite occurs as isolated fragments, the torbanite will fuse to form a coherent coke; if present in large quantities, as a continuous skeleton, the coke will be incoherent; in small to medium quantities, forming a continuous skeleton, the coking properties depend on hardness, as discussed by the writer in a previous paper (Dulhunty, 1941b). Soft matrosite tends to form a supporting structure during the first stages of coking, thus preventing fusion and giving an incoherent coke, while in the case of hard matrosite there is a complete breakdown in structure, which allows fusion and gives a coherent coke.



The results of thermal decomposition are affected by medium to large quantities of matrosite. The ratios of volatiles/fixed carbon and oil/organic matter are reduced, owing to the presence of free carbon in the matrosite; and the oil/gas ratio is reduced, if the proportion of humosite is high.

*Group C.*—The properties belonging to this group vary as a function of the quantity of the algal material present. Small amounts give even fracture parallel to the bedding, while large quantities produce the conchoidal fracture, typical of high-grade torbanite. In the case of torbanites with bright lustre, small quantities of algal material give a coarse, silky sheen; and large amounts produce a waxy sheen. Perfection of cleavage, parallel to the bedding, decreases with increasing quantities of gelosite and retinosite. The abundance of algal material plays an important part in the oil yield of torbanite. The eukerogenic and dyskerogenic nature of the organic matter, already described, plays an equally important part; but abundance determines high and low quality in both leucocratic and melanocratic types. Some leucocratic torbanites, containing eukerogenic algal material, yield less oil per ton than melanocratic types, owing to differences in the quantity of kerogen present. There is, however, a direct relation between the oil yield and quantity of kerogen, for given ratios of oil/organic matter and oil/gas. The abundance of organic matter also controls the results of proximate analysis for torbanites possessing any given ratio of volatiles/fixed carbon, although the ash content is always more or less inversely proportional to the quantity (by volume) of organic matter present.

*Genetical Relations between Influencing Factors.*—The three principal factors determining the foregoing groups of properties are themselves related to the fundamental principles underlying the formation of torbanite. The differentiation of algal sapropel, into eukerogenic and dyskerogenic forms, appears to have occurred during the accumulation of the algal material. The actual reason for the difference is not clear; but it probably involves a biological effect, due to the physical conditions existing during the algal development. It is evident, however, that the factor, influencing the properties of Group A, may be regarded as dependent upon the *environment of accumulation*.

The influence of the matrix, controlling the properties of Group B, involves the abundance, arrangement and hardness of the matrosite. Of these features, the first is the result of variation in the amount of silt introduced during deposition of the sapropel; the second is related mainly to the continuity of introduction of extraneous material; the third appears to be a function of inorganic cementation occurring during the metamorphism of the deposits. It follows that this factor is dependent upon the *environment of accumulation*, as well as the *environment of preservation*. The underlying causes of variation in the amount of algal material present, is directly connected with physical conditions, including water currents and the introduction of extraneous matter during the development of the alga. Thus, the factor influencing the properties of Group C is dependent upon the *environment of accumulation*.

It may be concluded that all the variable properties of torbanite, both of economic and purely scientific importance, are genetically related, and may be correlated with conditions prevailing during the accumulation and preservation of the algal sapropel, as summarized in Table 3.

#### *Genetical and Constitutional System of Classification.*

The properties of the different torbanites, belonging to all the known deposits in New South Wales, have been moulded by the combined influence of the three fundamental factors already described. The influence of each factor has varied throughout the development of the different deposits. It is evident that all torbanites must fall into two main divisions, depending on variations in the factor controlling the properties of Group A. These two divisions consist of the leucocratic and melanocratic types, containing eukerogenic and dyskerogenic organic matter, respectively. Each division may be subdivided on the basis of variations in the factor controlling the properties of Group B. The variation in this factor most suitable for the purpose of classification is the relative hardness of the matrosite, as this, giving bright and dull types, determines the diagnostic physical property of lustre. The abundance and arrangement of the matrix can be taken into account, if so desired, by creating special groups within the

subdivisions of bright and dull lustre. This added complication is unnecessary, however, unless required for special, technical purposes. Each of the four sub-divisions, formed by the bright and dull types of both leucocratic and melanocratic torbanites, may be split up into grades, on the basis of variations in the abundance of algal material, which is the factor influencing the properties of Group C. This factor controls the actual oil yield of the types belonging to each of the four sub-divisions; and it is suggested that three grades should be recognized, within each sub-division: namely, high-grade (above 70% algal material); medium-grade (40 to 70%); low-grade (below 40%). The relation between fracture and grade, for handspecimen identification, may be taken as follows: high-grade, conchoidal fracture; medium-grade, sub-conchoidal fracture; low-grade, rectangular fracture.

This system of torbanite classification is illustrated in Table 4. It provides for twelve types of torbanite possessing characteristic physical properties, accompanied by microscopical and chemical properties of specific nature. All the types are based on genetical and constitutional features, determined by the environments of accumulation and preservation. Handspecimen identification, in terms of the classification, is possible by means of diagnostic physical properties, as illustrated in Table 3. The particular grade, sub-division and division, to which the specimen is allotted, then serves as a

TABLE 4.  
Classification of Torbanite.

Basis for Differentiation.	Classification.											
	Carbonaceous sediments											
Original organic debris and environment of accumulation.	Carb. shales			Torbanites			Cannel			Coal		
<i>Divisions.</i>												
Environment of Accumulation.												
<i>Colour of Streak:</i>												
Leucocratic (light).												
Melanocratic (dark).												
<i>Sub-divisions.</i>												
Environment of Preservation and Accumulation.												
<i>Lustre:</i>												
Bright and dull.												
<i>Grades.</i>												
Environment of Accumulation.												
<i>Fracture:</i>												
Conchoidal (High-grade).												
Sub - conchoidal (Medium - grade).												
Rectangular (Low-grade).												

key to its genetical, constitutional and economic characteristics. For example, a specimen possessing conchoidal fracture, bright lustre and yellowish-white streak would be classified as *high-grade, bright, leucocratic torbanite*. Another specimen, possessing sub-conchoidal fracture, dull lustre and brown streak, would be a *medium-grade, dull, melanocratic torbanite*. A great deal of information concerning microscopical, chemical and economic features, could be deduced immediately from the association of other properties, as set out in Table 3.

In any one deposit, there is a tendency for all the torbanite to belong to the same division and sub-division; but variations frequently occur in grade. The classification, with respect to division, sub-division and prevailing grade, for the greater part of the torbanite in each of the New South Wales deposits, is given in the following list:

*High-grade, bright leucocratic.* Marangaroo (rich lens); Ulan.  
*Medium-grade, bright leucocratic.* Baerami; Reedy Creek; Tong Bong Mt.  
*Low-grade, bright leucocratic.* Marangaroo (bands on western side of seam).  
*High-grade, dull leucocratic.* Barigan.  
*Medium-grade, dull leucocratic.* Blackman's Crown; Marangaroo (main seam); Mt. Marsden.  
*Low-grade, dull leucocratic.* Cooyal Creek; Grimshaw's Seam; Ilford Range; Mornington; Wanganderry.  
*High-grade, bright melanocratic.* Coolaway Mt.; Hartley Vale; Mort's Upper Seam; Ruined Castle Seam; Wondo.  
*Medium-grade, bright melanocratic.* Joadja; Sugarloaf Mt.  
*Low-grade, bright melanocratic.* Mt. Blackheath.  
*High-grade, dull melanocratic.* Glen Davis (rich bands in seam).  
*Medium-grade, dull melanocratic.* Airly; Glen Davis; Mt. Tonalli.  
*Low-grade, dull melanocratic.* Mort's Lower Seam; Lamb's Seam; Victoria Falls.

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#### EXPLANATION OF PLATE VI.

- A. Torbanite, Joadja Deposit. Horizontal section, 25 diams. High-grade, showing closely packed algal colonies consisting mainly of gelosite, with retinosite body at centre.  
 B. Torbanite, Wollar Deposit. Vertical section, 60 diams. Medium-grade, showing algal colonies (gelosite) surrounded by relatively large amounts of opaque matrix (matrosite).  
 C. Torbanite, Baerami Deposit. Horizontal section, 50 diams. Medium-grade, showing the same features as B. Retinosite body at centre.  
 D. Transitional type, Katoomba. Vertical section, 60 diams. Intermediate between torbanite and bituminous coal. Algal colonies (gelosite) set in a groundmass of vascular-plant debris, including opaque, fragmentary fusain and continuous, translucent laminae of humic-degradation product.  
 E. Cannel coal, Airly Mount. Vertical section, 300 diams. Typical constitution of cannel. Rounded particle of resin (left-hand side), microspores (centre), opaque fragments of fusain, translucent laminae of humic-degradation product (lower right-hand corner) and translucent mineral matter.  
 F. Carbonaceous shale, Upper Coal Measures, Katoomba. Vertical section, 60 diams. Mineral matter in the form of large transparent grains and fine material in groundmass. Finely-divided, carbonized, organic matter forms opaque layers in groundmass.



- G. Transitional type, Reedy Creek. Vertical section, 60 diams. Intermediate between torbanite and cannel coal. Algal colonies in a groundmass which is similar in constitution to E.
  - H. Coal. Vertical section, 60 diams. Macrospore (upper left-hand side), microspores, fragments of fusain and large amounts of structureless, translucent humic-degradation product.
  - I. Torbanite—Cannel junction, Baerami. Vertical section, 15 diams. Cannel above and torbanite below, showing remarkably sharp line of demarcation between the two types.
  - J. Transitional type, Grimshaw's Seam, Capertee Valley. Vertical section, 60 diams. Intermediate between torbanite and carbonaceous shale. Algal colonies in a groundmass of opaque and translucent mineral matter with one spore fragment (lower right-hand side).
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